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TITLE: SINGLE-POINT DIAMOND-TURNED MIRROR PERFORMANCE BEFORE AND AFTER POLISHING

MASTER

AUTHOR(S): Jon E. Sollid

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LOS ALAMOS SCIENTIFIC LABORATORY
Post Office Box 1663 Los Alamos, New Mexico 87545
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SINGLE-POINT DIAMOND-TURNED MIRROR PERFORMANCE
BEFORE AND AFTER POLISHING*

Jon E. Sollid
University of California
Los Alamos Scientific Laboratory
Los Alamos, NM 87545

Abstract

The surface finish of a single-point diamond-turned (SPDT) mirror produced in 1977 on the large (2-meter swing) Excello lathe at the Union Carbide Corporation's Y-12 Plant in Oak Ridge, Tennessee, was such that it was not possible to do visible alignment using it. Therefore, it was necessary to polish the mirror by hand. This was done at the University of Arizona. The intent was to remove the high ridges in the SPDT mirror but not to degrade the figure. Both interferometric and encircled energy measurements were made on the mirror before and after polishing. The mirror was an f/2 off-axis parabola 39.37 cm in diameter. The equation describing the generator of the mother parabola is $y^2 = 309x(\mathrm{cm}^2)$ and the center of each off-axis sister mirror is at x = 7.64 cm, and y = 48.59 cm. After polishing it was possible to align it using techniques which employed visible light.

Furthermore, the polished mirror was about 20% better as far as the rms surface figure was concerned, although cosmetically the surface finish appeared visibly degraded after polish.

Description of Apparatus

The encircled energy was measured using a 16-inch-diameter collimator which was operated both in the visible and at 10.6 um. The device is a modified Davidson Model 279. The output is annular with 39.4 cm outside diameter and 3.8 cm inside diameter.

Alignment was done in the visible and checked for collimation with a lateral shearing interferometer. The output was planar to better than $\lambda/10$ at 633 nm, peak-to-valley (p-v). The f/2 off-axis parabola was mounted on the test rail. The parabola was rough aligned using the version of the Hartmann test (devised by Quentin Klinger, EG&G, Los Alamos) which is used on both the Gemini and Helios laser systems. The final alignment was achieved using the star test whereby the image is examined microscopically.

The visible source was replaced with a 10.6-um radiation source (a Model 941 Sylvania) and the output examined for uniformity with a pyroelectric vidicon. Encircled energy measurements were made as illustrated in Fig. 1. The detectors were thermistors and the pinholes were changed manually. The focal volume was searched out for each pinhole by translating the pinhole in x, y, and z until a maximum ratio was obtained. The synchronous chopper had reflecting blades so that the reflected signal could be seen by detector D_2 which provided the reference. It read the integrated signal over a square millimeter. The pinholes were 10, 25, 50, 75, 100, 150, 200, 300, and 400 um in size.

Figure 2 shows a schematic representing the optical layout of the experiment. The focal length of the collimating parabola is 107 inches and the focal length of the mirror under test was 31 inches. Thus, the illuminating pinhole is reimaged at the focal plane of the off-axis parabola, but demagnified by a factor of 31/107. The diffraction-limited spot size for the off-axis f/2 parabola is about 50 um. The image of the largest pinhole used in the collimator was less than half the diffraction limited spot size of 60 um. What we observe in the focal plane of the test mirror is essentially its diffraction performance.

Figure Measurements

Figure 3 shows plots of the theoretical diffraction limited performance and the measurements made before and after polishing. These results are reproducible to better than 2%. Alignment was verified by tipping and tilting the parabola in the meridonal and tangential planes until the highest signal was obtained at the focus through a 100-um pinhole.

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The top curve in Fig. 3 is the theoretical diffraction limited performance. About 81.4% of the energy is contained within the first null in the impulse response or point spread function (PSF). The curve drawn through the triangles represents the encircled energy measured on the as-machined parabola. Note that 65.6% of the energy is contained within the first null of the PSF. The ratio 65.6/81.4 = 0.81 can be thought of as the Strehl ratio for the beam. It is a measure of the optical quality of the beam. From it one may infer the rms figure error in the optical component via the relationship

$$S = \exp - (k\delta)^2 \quad ,$$

where $k = 2\pi/\lambda$, and δ is the rms wavefront error.

Thus, for the as-machined case we obtain $\delta = 0.0739\lambda$ at 10.6 µm (0.7833 µm or 30.84 µin.). This compares favorably with 0.0558λ rms at 10.6 µm (0.5915 µm or 23.29 µin.), which was measured for a sister mirror. By that, we mean that it was cut at the same time and in the same fixture. There were six such sisters in each parent fixture which were all turned simultaneously. The measurement on the sister mirror was made interferometrically in the visible, and the reduction was done using the FRINGE II computer code.[1]

The curve connecting the full circles was obtained on the polished mirror. It gives a Strehl of 0.67 and an rms figure error of 0.0594λ rms at 10.6 µm (0.6296 µm or 24.79 µin.), or about a 20% improvement in surface figure.

To put these figure measurements in perspective, they represent a two- or three-year old technology. The mirrors were cut on a machine of very large capacity (the Excello). Such a large machine will not produce the best surface finish. The machines have been improved and are expected to meet the specifications for the Antares laser mirrors which are 3 to 6 µin. rms.

Experimentally it was noticed that there was no difference in signal with the 400-µm pinhole in or out. The detector size is about 1000 µm. Therefore, all the c ves above were made by normalizing the data to the theoretical value at 400 µm. It should be noted that all the experiments say is that there is little change between the energy collected between 400 µm and 1000 µm. If there is a broad "wing" to the PSF these measurements are insensitive to it.

Conclusions

In conclusion, the polishing which this mirror received (20 hrs polishing, 60 hrs testing) not only improved the surface finish, thereby allowing alignment in the visible, but improved the surface figure by a modest 20%.

References

1. V. K. Viswanathan, J. E. Sollid, W. S. Hall, I. Liberman, and G. Lawrence, "Interferogram Reduction and Interpretation as Applied to the Optical Analysis of a Laser Fusion System," ASTM Symposium Proceedings, STP666, 1978, pp. 98-105.

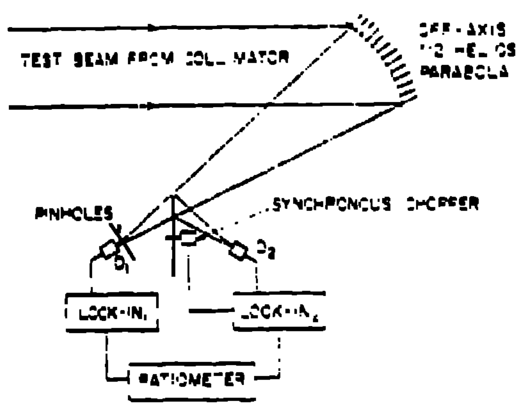

Fig. 1. Schematic diagram illustrating the optics used to produce the collimated test beam used to make the encircled energy measurements.

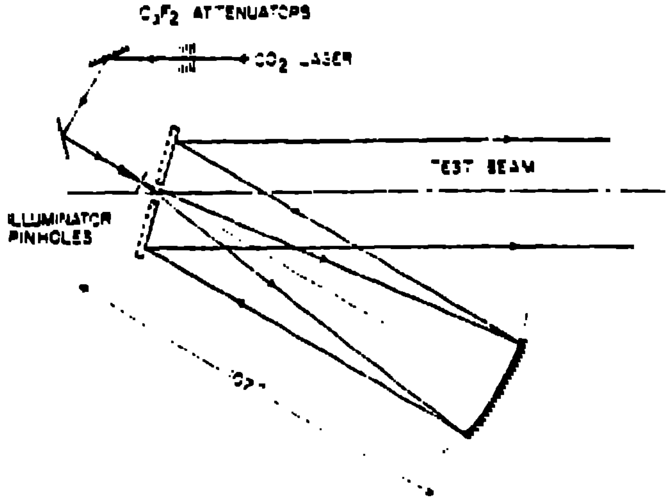

Fig. 2. Schematic diagram illustrating the apparatus used to make the encircled energy measurements.

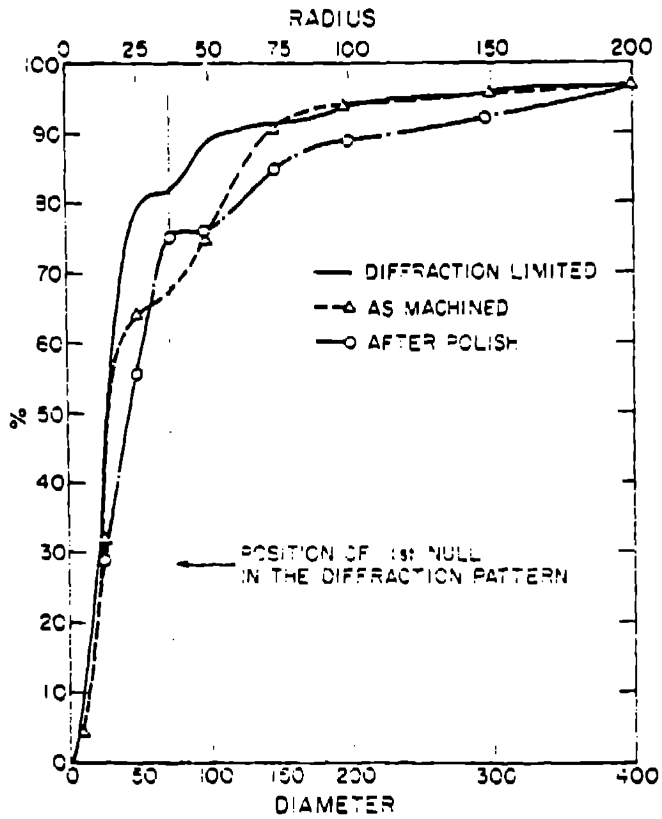

Fig. 3. Encircled energy vs pinhole diameter, three cases:
A. Diffraction limited
B. As-machined
C. After polish